BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B71 02019

SUBJECT: Need for Calibration of the Lunar Model Used in the Apollo 14 T+24 Lighting Review - Case 310

DATE: February 10, 1971

FROM: R. Troester

ABSTRACT

At the December 1, 1970 review of lunar visibility during a T+24 landing, Flight Crew Support Division presented a series of photographs of a lunar model which exhibited much higher surface visibility than had been expected for high-sun conditions. Comparison of recently published reflection data on the model with the standard lunar photometric functions leads to the tentative conclusion that slope contrast downrange of the zero-phase point may be up to ten times that predicted for a high-sun landing on the lunar surface. For low-sun landing simulations, the glass bead coating employed on the model will be useful in simulating the surge in lunar surface brightness around zero phase. Before being used in high-sun simulations for Apollo 15 and later missions the glass bead model should be further calibrated with the lunar photometric function.

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(NASA-CR-116936) NEED FOR CALIBRATION OF THE LUNAR MODEL USED IN THE APOLLO 14 T PLUS 24 LIGHTING REVIEW (Bellcomm, Inc.) 12 p

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MEMORANDUM FOR FILE

Introduction

On December 1, 1970 a telecon review was held between NASA Headquarters and MSC on the problems involved in planning for a T+24 hour launch opportunity for the Apollo 14 mission to Fra Mauro. Reference 1, recently published, documents the work presented in that review. Although directed to the Apollo 14 mission, the results of the review and the methods whereby they were obtained are obviously of interest in planning a T+24 landing on Apollo 15 and later missions.

The major difficulty encountered in planning a T+24 landing lies in the present uncertainty in predicting the ability of the astronaut to recognize landmarks during descent. With the sun 13° higher in the sky than in the nominal plan (i.e., at about 23° elevation), the washout area moves into the landing zone, shadows become fewer, and surface visibility is seriously degraded. Past analytical and model studies, which were not oriented to a specific site, had predicted low but acceptable obstacle visibility and marginal landmark visibility. For the review, MSC concentrated its efforts on the Fra Mauro site to attempt to determine specifically the landmarks available for Apollo 14. For their presentation, Flight Crew Support Division (FCSD) displayed a series of photographs of a Fra Mauro model taken at several points during a simulated LM descent which exhibited astonishingly good contrast even at high sun angles. For example, features much smaller than Weird Crater (150 ft.) were clearly visible from 4000 ft. simulated altitude and no downrange "washout area" such as had been predicted by analytical visibility calculations could be seen in the model photographs. The analytical calculations had been thought to be conservative, but not to the extent indicated by the new model study. Clearly, the study would indicate that there is no high sun visibility problem, except perhaps near 500 ft. altitude when the astronaut's line of sight to the touchdown spot would pass closest to zero phase. At issue, then, is the question as to which best represents the lunar visual environment, the analytical or the model approach. Unfortunately, insufficient information about the photometric characteristics of the FCSD model is presently available to answer that question.

(Note that the basic conclusion reached at the December 1 review that a T+24 landing at Fra Mauro is acceptable is not in contention, as this conclusion was confirmed independently by other means. But the extent to which the astronauts would be able to detect surface features near the landing site under high sun conditions and hence the final approach logic they would use are still uncertain.)

FCSD Model and Light Source

The model used for the review, according to information supplied by FCSD, is the prototype urethane version of the Apollo 14 Fra Mauro terrain models constructed by the Army Topographic Command for the LMS simulators at Houston and Cape Kennedy. To prepare it for photography, the porous urethane was first painted with a 50% reflective gray paint to seal the surface and then uniformly sprayed with electrostaticly charged glass beads. The beads rather sparsely covered the surface (only about 8% of the total surface area) and, acting in a fashion similar to a beaded projection screen, added a retroreflective component to the largely diffuse light scattered from the painted model. The glass bead technique had been developed for FCSD by Lockheed Geophysics Branch for potential use on the terrain models in the LMS and considerable work had been done in choosing the bead size (40-60μ), index of refraction, and percentage of coverage in order to give a good simulation of the surge in lunar brightness at zero phase. Glass beads have not been used before in lunar visibility simulations although they had been studied even before Apollo 11 as a possible component of the lunar surface material (Reference 2). Instead, most investigators have used a type of fluffy powder, such as cupric oxide or Portland cement, which also retroreflects incident light in a marked fashion. The lunar soil itself, interestingly, seems to be made up both of powder and of microscopic glass spherules.

Lighting for the model was from a xenon point-source lamp with no collimation of the beam. The point source provided the sharp shadowing required for the simulation while the lamp was placed far enough away from the model so that, reportedly, the lighting changed much less than 5° in azimuth over a four-foot diameter area of the model centered on the landing site. No variation in shadow direction due to this effect was visible in the model photos. Absence of collimation in the light source will also tend to broaden the zero-phase area. This broadening, however, will slightly lower contrast values on the model, especially at higher simulated altitudes, and will make the simulation somewhat more conservative than otherwise.

Model Reflection Characteristics

At the December 1 review, the curves reproduced here in Figure 1 were presented. This and a similar figure in Reference 1 contain all the presently available information about the reflection characteristics of the model. The two halves of Figure 1 are polar plots, one for the nominal 10° sun elevation and one for the 23° elevation. The solid curves give the percent reflectance or relative brightness of the glass model (radial distance in the plot) as a function of viewing elevation angle. Such a curve is called an indicatrix and is characteristic of the surface texture of a material. Notice that maximum brightness is reached when the viewing angle is equal to the sun angle, that is, at zero phase angle. The dashed curve in each plot is the relative brightness of the average lunar surface for those same viewing angles. For clarity in the presentation, the average lunar brightness curve was expanded four times from a peak reflectance (or albedo) of 7% to 28%. The precise value of peak reflectance used for the lunar surface or the glass bead model is not significant since the apparent brightness of the model can be modified by filters, lighting, or exposure time. What is significant is the variation in brightness with angle and slope, as will be discussed below.

The curves of Figure 1 illustrate the general retro-reflective peak which is characteristic of both the glass bead model and the lunar surface. The information about the glass bead model contained in these curves, however, is entirely restricted to the case in which the eye, light source, and surface normal lie in the same plane. Model brightness and contrast values are difficult to estimate due to the small amount of data.

Generally in the Ranger, Orbiter, and Apollo programs lunar brightness and contrast values have been calculated according to one of two lunar photometric functions derived by JPL from earth-based Russian photometric measurements. These are the so-called Fedorets function and the Lunar Reflectivity Model (LRM). An analytical model, called the Hapke function, has also seen some limited use (Reference 3, 4). These functions are plotted in Figure 2 along with the average lunar brightness curve of Figure 1. All the curves have been adjusted to indicate equal brightness at zero phase. As in Figure 1, radial distance from the center of the figure represents percent reflectance of light from the lunar surface for that viewing angle. The FCSD lunar brightness estimate lies between the Fedorets function and the LRM for low viewing angles but becomes much brighter for viewing above the sun line. The Hapke function, on the other hand, lies between the Fedorets function and the LRM at high viewing angles but is obviously in error below the sun line since it predicts maximum brightness for viewing at a glancing angle to the surface rather than at zero phase. Because of this characteristic it cannot be employed in high sun landing analysis.

The rather large separation between the Fedorets and LRM curves at some angles is a measure of our present uncertainty in predicting lunar brightness levels. Nonetheless, as these two functions are the best sources of lunar photometric data, an attempt was made in Figure 3 to match them to the FCSD curve for the glass bead model. For a best fit over the whole range of viewing angles, the three curves were matched at a point 5° above the sun line. In a steep descent the landing site will be viewed at about a 25° angle. Features uprange of the landing site will be seen at steeper angles and features downrange will be seen at shallower angles. Except for very high viewing angles the glass bead model can be adjusted to match the brightness of the lunar surface fairly well for the two sun angles presented. An area of one or two degrees around zero phase on the model will then be much brighter than predicted on the moon. The lunar photometric functions are known to be pessimistic in this area, however, and in any case, in the simulator the camera shadow will probably obscure most of the overly bright region.

The small peaks observable in the glass bead curves in Figure 3 are due to the "rainbow effect" produced by any transparent spherical scatterer; the indicated points on the curves are at the proper angles for the primary bow if the index of refraction of the glass beads is about 1.5. These "rainbows" are clearly visible in the model photographs as well as in Figure 3, although apparently not at the same viewing angles given in the figure. However, as there is a wide angular separation between the bows and the landing site, the presence of the bows does not significantly affect the validity of the simulation.

Model Contrast Values

In general, surface brightness is not the controlling parameter in object visibility. Of more importance is the photometric contrast, defined as the difference in brightness between an object and its background, divided by the brightness of the background, or

$$C = \frac{B_O - B_B}{B_B} .$$

Contrast defined in this fashion is positive if the object is brighter than its background and negative if it is darker. Objects of equal size with contrasts of equal absolute value are equally visible. Shadows on the moon have a very high contrast of -1 and when present greatly aid detection and recognition. At high sun, shadows are largely absent and much of the scene contrast is due to a difference of slope such as that between the wall of a crater and the surrounding terrain.

From Figure 1 it is difficult to draw conclusions about the overall reflection characteristics of the glass bead model. Since curves for two different sun elevations are given, however, it is possible, given some assumptions, to calculate representative contrast values. In Figure 1 a difference in brightness between points on the two curves with the same phase angle can be considered equivalent to the difference in brightness between a 13° (23°-10°) slope and the surrounding terrain. This slope is a typical average value for an interior crater wall. In the calculation of the corresponding contrast values the sun elevation is taken as 23°; the 13° slope faces away from the observer.

In Figure 4 the contrast value calculated for this "crater wall" from the glass bead model, along with similar curves for the LRM and Fedorets function, is plotted as a function of distance along the lunar surface, assuming the spacecraft at an altitude of 4000 ft. The equivalent viewing angles for these ranges are also shown. As a guide, several landmarks are indicated at the appropriate ranges, although these landmarks are not located exactly on the ground track passing through the spacecraft nadir and the zero-phase point for which the contrast values have been calculated.

In interpreting Figure 4, notice that visibility should be quite good, due to the presence of shadows, from the bottom of the LM window up to the zero phase point in the field-of-view, even though slope contrast on the model is fractionally less than calculated for the moon using analytical methods.

Downrange of the zero-phase point the picture changes. Here the glass bead model seems to provide up to ten times the slope contrast predicted by the LRM and Fedorets functions. Brightness values are also reversed from those predicted for the moon: a slope facing away from the observer appears a slightly darker shade of gray than its surroundings (negative contrast) rather than a slightly lighter shade (positive contrast). This last difference from the predictions is not significant, however, considering the inaccuracies in the photometric functions themselves. The contrast predicted by the LRM and Fedorets function is low enough to indicate considerable difficulty in detecting and recognizing equal-albedo craters in the washout region while that calculated for the glass bead model is high enough to explain the very good visibility evident in the model photographs.

Conclusions

A comparison of the available data for the glass bead coated lunar model with currently used lunar photometric functions has shown that the glass bead model can be made to match the lunar surface reasonably well in brightness over the angular range of interest in a lunar landing. In training for landing at low sun elevations, where geometrical shadows provide the major detection clues, the glass bead technique will enhance the fidelity of the simulation due to the zero-phase brightening it introduces into the model. Use of glass beads in the simulator for low-sun training should not materially change present model contrast values, which tend to be somewhat pessimistic due to light scatter into the shadow areas and the restricted brightness range of the LMS TV system.

Before the glass bead model is employed for high-sun simulation training, it may require further calibration and adjustment since present data seem to indicate that when observed directly it provides much greater contrast downrange of zero-phase than expected for the moon under these lighting conditions. When installed in the LMS simulator and viewed through its TV system, a glass bead model might more nearly match the lunar scene. Further measurements of the model's reflection characteristics over a much wider angular range are necessary to decide this question.

2013-RT-jab

Robert Troester
R. Troester

Attachments
Figures 1 through 4

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3. Willingham, D., "The Lunar Reflectivity Model for Ranger Block III Analysis," JPL Tech. Report No. 32-664, November 2, 1964.

4. Shorthill, R. W., Saari, J. M., et. al., "Photometric Properties of Selected Lunar Features," Boeing Company Space Division, September, 1968, NASA Report No. N69-10396.

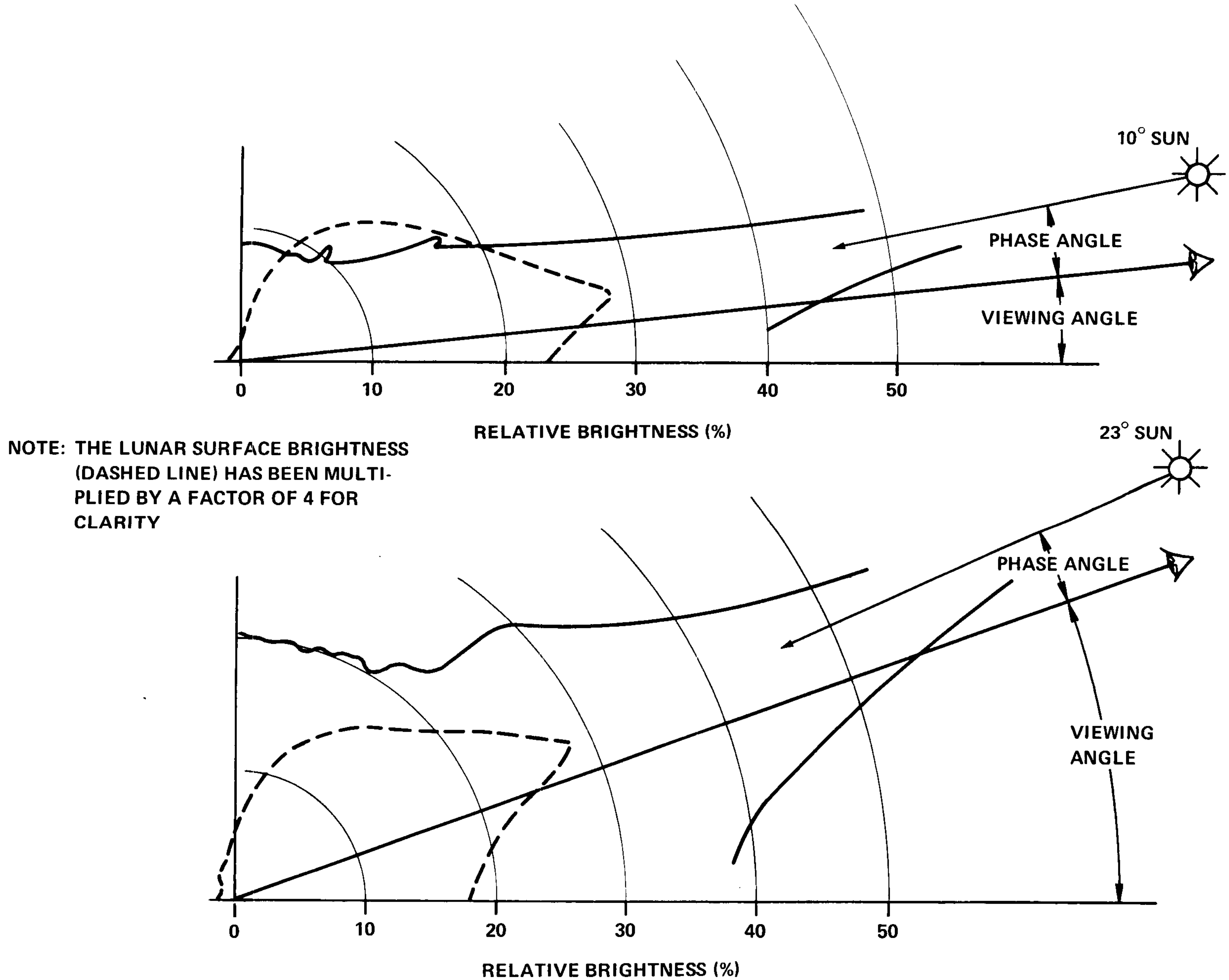

FIGURE 1 - POLAR PLOT OF GLASS BEAD MODEL BRIGHTNESS (SOLID CURVE) AND FCSD LUNAR SURFACE BRIGHTNESS (DASHED LINE) AS A FUNCTION OF VIEWING ANGLE

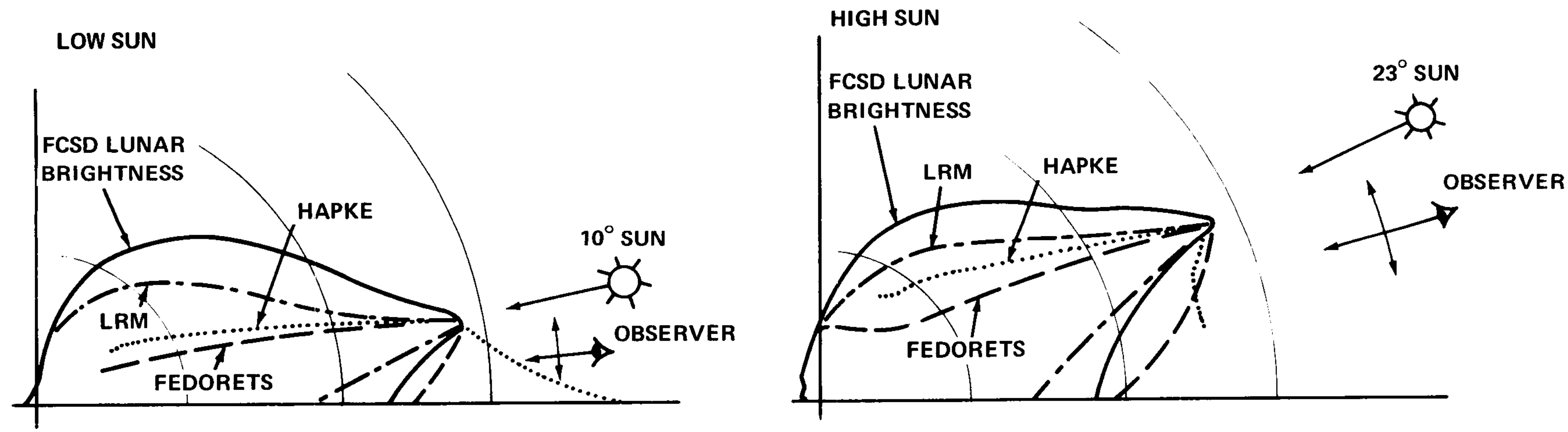

FIGURE 2 - COMPARISON OF FCSD LUNAR BRIGHTNESS WITH STANDARD LUNAR PHOTOMETRIC FUNCTIONS

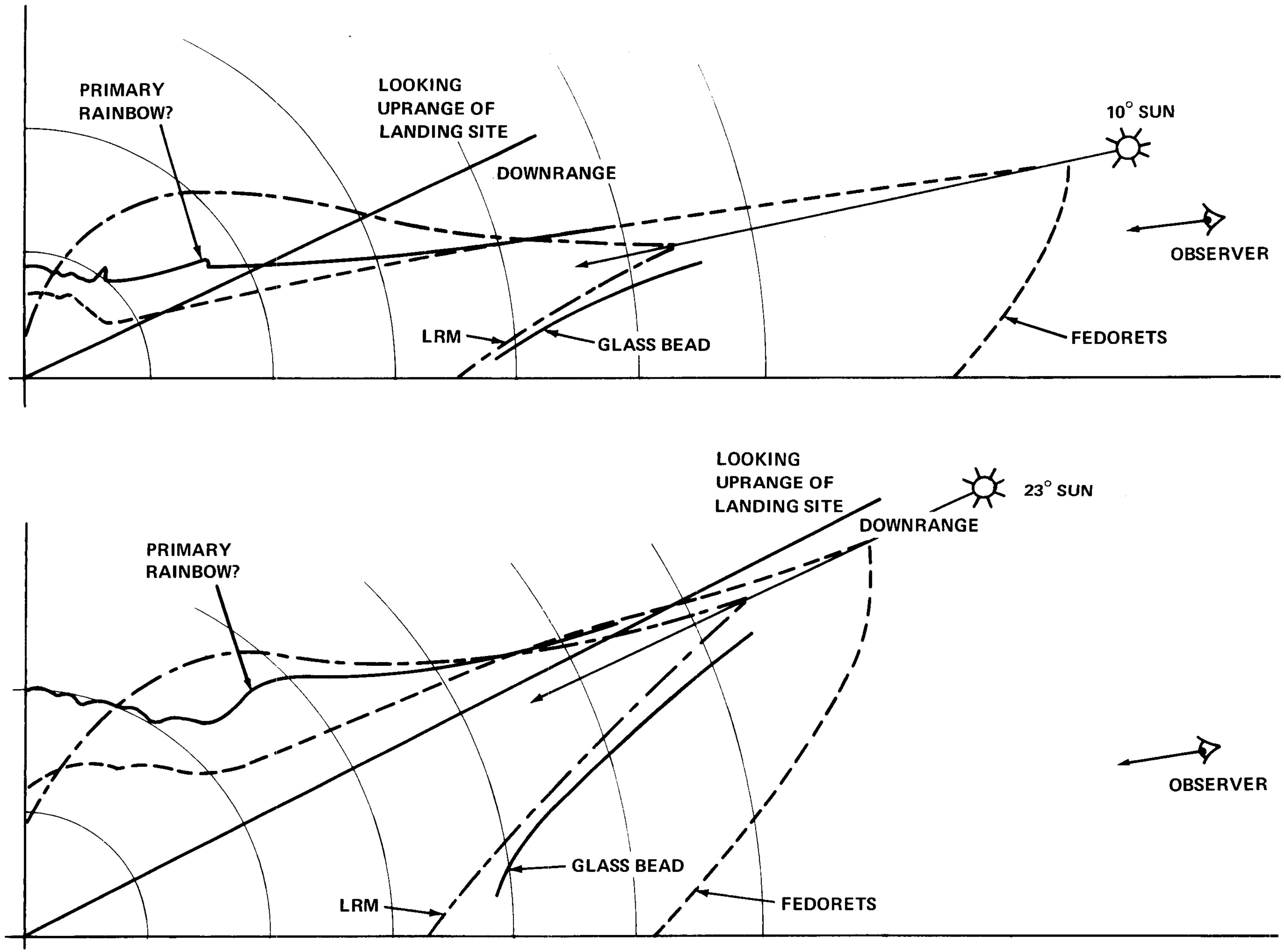

FIGURE 3 - COMPARISON OF BRIGHTNESS OF FCSD GLASS BEAD MODEL WITH STANDARD PHOTOMETRIC FUNCTIONS

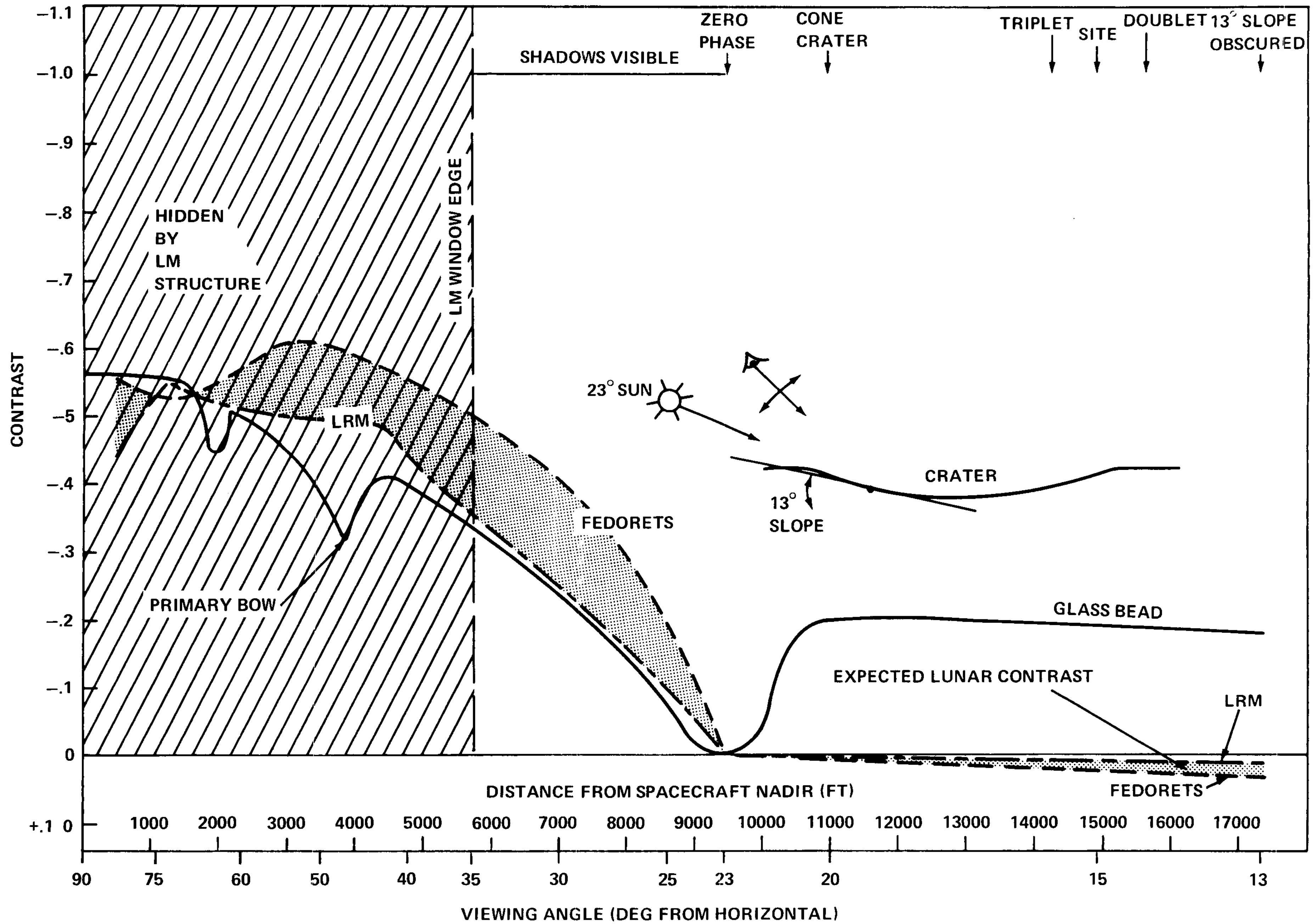

FIGURE 4 - CONTRAST OF 13° SLOPE ON LUNAR SURFACE VIEWED AT 4000 FT.
ALTITUDE DURING T + 24 DESCENT

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